Helios Mission Support

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Project Helios, named after the ancient Greek Goddess of the Sun, is a joint space venture being undertaken by the Federal Republic of West Germany and the United States of America. Two unmanned scientific satellites will be placed into heliocentric orbits: the first during mid-1974, and the second in late 1975. The history of this Project, its mission objectives, and a general description of the spacecraft were given in previous articles. This article initiates a more detailed description of the spacecraft's radio subsystem in order that the reader may more thoroughly understand the interrelationships between spacecraft design and the planned capabilities of the Deep Space Network (DSN). Specifically, this article provides a functional description of the Helios Telemetry System.

I. Introduction

This is the third of a series of articles pertaining to Project *Helios*. The first two articles (Refs. 1 and 2) provided an overview of the Project organization, the spacecraft physical configuration and radio system design, the spacecraft trajectory to within 0.25 AU of the Sun, and the support requirements placed upon the Deep Space Network. This article will treat some of the significant highlights reported during the Fourth *Helios* Joint Working Group Meeting (held at the Goddard Space Flight Center April 28 through May 4, 1971) and will initiate a series of detailed descriptions of the spacecraft radio system and its interface with the Deep Space Network.

II. Significant Developments at the Fourth *Helios* Joint Working Group Meeting

A complete description of the proceedings of the Fourth *Helios* Joint Working Group Meeting are contained in its minutes (Ref. 3). However, it is appropriate to highlight some of the more significant developments resulting from this meeting—particularly with respect to the interface between the *Helios* spacecraft and the Deep Space Network.

A. *Helios* Spacecraft Radio System Design Review

The *Helios* Project Office provided the various working subgroups with the first comprehensive description of the contemplated spacecraft radio system design and, in turn, requested that the working group membership respond with a technical critique. It was the general reaction of the TDS Subgroup (see Fig. 1, p. 20, Ref. 1) that the Project Office had made considerable progress in developing the spacecraft radio system design since the Third *Helios* Joint Working Group Meeting. Particularly notable was the maturity of the design as depicted in the level of detail and the thoroughness with which it was presented. While few, if any, major difficulties were detected in the technical review, several features were disclosed which will be of interest to the reader.

1. Block diagram changes. Two design changes were introduced which will slightly modify the block diagram depicted in Fig. 3, p. 24, Ref. 1. It is suggested that the reader pencil the following changes into his copy: First, the two solid-state 1-watt amplifiers have been replaced by one 0.5-watt, low-power amplifier which will still have a capability of being coupled directly to the diplexer/antenna system. This single 0.5-watt amplifier will provide the spacecraft low-power mode. Second, the 20-watt Traveling-Wave-Tube (TWT) amplifiers have been replaced by a combination 10/20-watt TWT amplifier to provide either the medium-power or high-power mode of transmission from the spacecraft to the Earth. The connection between the combination medium/high-power TWT amplifiers and the diplexer/antenna system remains as shown in Fig. 3 of Ref. 1.

2. Two-way, non-coherent mode. The second significant design change in the spacecraft radio system relates to the two-way, non-coherent mode of operation of the transponder. In previous flight projects supported by the DSN, the establishment of an uplink to the spacecraft has caused an automatic switching of the transponder from a one-way (non-coherent) mode into a two-way coherent mode, while the loss of an uplink would cause the automatic reversal of the process. While the latter feature is incorporated into the present *Helios* transponder design, the establishment or re-establishment of the uplink does not automatically create a coherent mode—rather, a command must be sent to the spacecraft to cause it to change from the two-way, non-coherent mode into a two-way coherent mode, as depicted in Fig. 1 of this article. This was done for operational considerations since, during the Step I and Step II maneuvers (see previous articles, Refs. 1 and 2), there is a reasonably high probability of momentary uplink and/or downlink dropouts due to antenna pattern nulls. To avoid sudden jumps in downlink frequency caused by repetitive switching between the voltage-controlled oscillator (VCO) and the onboard very stable oscillator (VSO), the transponder is maintained in the two-way, non-coherent mode during maneuvers and other critical events such as boom deployment, etc. While the foregoing feature is advantageous insofar as the mission operations design is concerned, it does present a new and novel acquisition procedure to the Deep Space Network. A preliminary concept of the new DSN acquisition technique is shown in Fig. 2; however, the time associated with the major steps is only an initial estimate which, hopefully, will foreshorten with further study and experience with this new situation. The time from spacecraft rise to the establishment of two-way, non-coherent operation (shaded diamond of Fig. 2) is dependent upon flight conditions and is apt to be the greatest for the initial DSN acquisition where the tracking rates and other uncertainties are the greatest, and a minimum later on when the trajectory and hence station predicts are well known. However, it will always take several telemetry frames to establish frame synchronization in the DSS Sequential Decoder.

The minimum time between two-way, non-coherent operation and two-way coherent operation (shaded circle in Fig. 2) is a function of three independent factors: (1) the two-way light time for the signal to reach the spacecraft and return, (2) the time required for the spacecraft bit synchronizer to lock-up to the command idle stream prior to initiating actual commands (which is still undergoing study by the Project Office), and (3) the time it takes to re-establish downlink lock at the DSS after loss of the spacecraft's non-coherent signal.

3. Command system. While the details of the *Helios* spacecraft command system will be treated in the next article, it is significant to note that with the present design concept it is necessary to enter an idle stream of 001's into the spacecraft command bit synchronizer for several minutes prior to transmitting the command sync word and command instruction into the spacecraft. This has several operational implications:

(1) The initial DSN acquisition during the Near-Earth Phase must take this time delay into account.

(2) This time delay will also be a factor during handovers between DSSs during the cruise phase of the mission.

(3) During routine tracking operations, it may be necessary for each DSS to continuously transmit the 001 idle stream to the spacecraft in order to ensure rapid command access should the need arise.

(4) Any inadvertent interruption of the uplink will necessitate the re-establishment of bit synchronization aboard the spacecraft. Inadvertent uplink dropouts could be caused by a DSS transmitter overload trip or an unexpectedly deep null in the spacecraft antenna pattern. Known loss of uplink will occur during solar occultations where re-establishment of the command bit synchronization may be further delayed due to solar corona effects.

The foregoing factors do not impair the basic compatibility between the *Helios* spacecraft and the Deep Space Network; however, they must be considered in designing the mission sequence.

B. Telecommunication Milestone Schedule

Another significant Fourth *Helios* Joint Working Group Meeting item was the distribution of the Working Schedule for the Spacecraft Telecommunications Subsystem. This is shown in Fig. 3. Even though *Helios-A* is scheduled for launch in mid-1974, it is noted that Spacecraft Telecommunications Subsystem hardware activity commences early in 1972. One of the first activities will be compatibility tests between the Engineering Model of the spacecraft radio system and the Deep Space Network, conducted at JPL's CTA 21 facility. This test, which will span approximately two weeks, will establish the basic compatibility between the spacecraft radio subsystem hardware and the DSN. It is scheduled for this early date in order to allow time to make design changes in the spacecraft hardware should any significant incompatibilities be detected during these first compatibility tests. Following this, the Prototype Model spacecraft will be constructed. The Prototype Model will be a complete spacecraft in every detail, including the use of flight-qualified components. Because of this, the Prototype Spacecraft is scheduled to be shipped to California where it will undergo match-mate tests with the launch vehicle at San Diego, and thence undergo environmental and compatibility testing and calibration at the Jet Propulsion Laboratory, using operational software in the SFOF computers. The prototype tests are scheduled for the fall of 1973. The Flight Spacecraft are not scheduled to be processed through JPL, but rather to be shipped directly from Germany to Cape Kennedy. As a consequence, compatibility testing and spacecraft calibration for the Flight Spacecraft will be conducted at Cape Kennedy using DSS 71. Since Cape Kennedy does not have environmental test facilities comparable to JPL, it will not be possible to conduct all of the tests performed on the Prototype Spacecraft; however, all hardware and software compatibility tests performed on the prototype will be repeated using the Flight Spacecraft under the ambient conditions existing at the Cape. Considering budget and schedule constraints, this appears to be a reasonable compromise.

C. Near-Earth Phase Study Group Meeting

Following the Fourth *Helios* Joint Working Group Meeting, the second and final meeting of the Near-Earth Phase Study Group was conducted at the Goddard Space Flight Center during May 5–7, 1971. The principal objective of this latter meeting was to establish whether or not a viable near-Earth sequence of events could be established which would permit the activation of selected science instruments aboard the spacecraft in time to make magnetopause measurements in the region from 13 Earth radii to lunar distance. To accomplish this, the Study Group selected one typical trajectory (i.e., a 60-degree launch azimuth using a *Titan/Centaur* launch vehicle) and the latest available information generated by the Study Group membership together with information received during the Fourth *Helios* Joint Working Group Meeting. The Study Group succeeded in generating such a sequence of events for the selected Near-Earth Phase Mission Profile, and the results of this effort are presented in Ref. 4. Included in the list of constraints used by the Study Group was the acquisition procedure described above in *Section II-A-2*. This constraint, together with the need for the Mission Operations Team to carefully monitor and possibly send over-ride commands to the spacecraft during boom deployment, delayed the planned initiation of the two-way, coherent transponder mode of operation until spacecraft separation plus 70 minutes. This, in turn, will delay somewhat the DSN's ability to generate an early spacecraft trajectory for the purpose of computing station predicts and for use by the Mission Operations Team during the Step II manuever. The full impact of such a delayed start in the two-way, coherent mode of operation is still under study by the DSN; however, the situation is not considered serious provided ETR radar metric data are available from the C-band transponder aboard the TE-364-4 third stage. The results of the DSN study will be published when they become available.

III. *Helios* Spacecraft Telemetry Subsystem

A detailed description of the entire *Helios* Telemetry Subsystem is too involved for treatment in a single article, so it will be presented in logical or associated segments in several future articles. The present discussion is intended to acquaint the reader with the functional structure of the *Helios* Telemetry System and its major interfaces with other portions of the spacecraft. This description, together with a similar one covering the Spacecraft Command Subsystem in the next issue, should then permit a meaningful discussion of the various *Helios* telecommunications modes and their performances analyses.

A. General

The *Helios* spacecraft employs one telemetry channel to transmit both science and engineering data back to Earth. Both data types are convolutionally encoded[1] and modulated onto a single 32,768-Hz telemetry subcarrier, which, in turn, is phase-modulated onto the S-band downlink carrier. The combined science and engineering information data rate may be varied from 8 bps to 4096 bps,[2] in

[1]An uncoded mode is available for use during the Near-Earth Phase.

[2]At the present time, the DSN is limited to 2048 bps convolutionally coded telemetry processing in real time.

steps of a factor of two. The onboard science requirements dictate that the telemetry bit error rate (BER) not exceed 10^{-5}, with a maximum frame deletion rate of 10^{-4}. To accomplish this, the telemetry is convolutionally encoded at rate ½, using a Massey code with a constraint length of 32.

In addition to the foregoing real-time requirements, there is a mission requirement to be able to store telemetry onboard the spacecraft during blackout periods caused by solar occultation and/or during periods of particularly high solar activity. The latter is known as the Shock mode of operation which may be employed whenever it is desirable to obtain spacecraft science data with a higher time resolution than that permitted by the information bit rate being telemetered to Earth in real time at that particular moment. Under these circumstances, the Shock data (only) from the onboard science experiments are routed to the 5×10^5-bit core memory at a 4- to 16-kbps rate for storage, with provision for a later playback at a bit rate compatible with the telecommunications signal margins available at the time.

B. Functional Block Diagram

The method employed by the *Helios* spacecraft to meet the foregoing real-time and non-real-time telemetry requirements is depicted in Fig. 4. The real-time science and engineering data (lower lefthand corner) may be in either digital or analog form. The first step is, therefore, to digitally encode it in a manner that will permit further processing. The data is then fed to the Distribution Unit which formats it according to the telemetry mode selected, thence it is fed to the Convolutional Encoder. The output of the Convolutional Encoder, which is a symbol stream running at twice the rate of the original information bit stream, is then modulated onto the 32,768-Hz telemetry subcarrier (lower righthand corner of Fig. 4), which, in turn, is routed to the S-band phase modulator for transmission to Earth. The timing and synchronization of all of these operations is controlled by a single crystal oscillator within the telemetry control unit. This crystal oscillator also generates the 32,768-Hz telemetry subcarrier frequency. Because of this, all bit rates (or symbol rates) in the *Helios* Telemetry System are coherent with the telemetry subcarrier frequency. This coherent relationship, while advantageous from a spacecraft radio system design viewpoint, may produce interference when the data are processed through the Subcarrier Demodulator Assembly (SDA) at the DSS. Therefore, this will be one of the areas receiving particular attention when the *Helios* Engineering Model telecommunications subsystem undergoes compatibility tests in CTA 21 in early 1972.

Science and engineering blackout data enter the *Helios* Telemetry System in much the same manner as real-time data except, in this case, the Distribution Unit routes the data to Core Storage instead of to the Convolutional Encoder. This change in routing is activated by the Mode Registers when so instructed by ground command. Following the blackout period, another ground command can be sent which causes the Mode Registers to retrieve the science and/or engineering data from Storage by returning it to the Distribution Unit, which, in turn, presents it to the Convolutional Encoder for processing to Earth in a manner similar to that for real-time telemetry.

Shock data, which is defined as a sudden change in solar activity, can occur at any time throughout the spacecraft's heliocentric orbit. When the presence of a shock is detected by the science instruments, a *Shock Identification Pulse* is sent to the "Encoder Control Unit," which, in turn, enables the parallel entry of shock data into the Telemetry System. Like real-time data, the shock data is first digitally encoded but at a much higher rate (4 to 16 kbps). The digitally encoded shock data is sent by the Distribution Unit into Core Storage. As previously implied, this can be done in parallel with the spacecraft sending real-time telemetry data to Earth. The shock data so accumulated in Core Storage may or may not be recalled for playback to Earth—depending upon the particular circumstances involved. If the shock data has not been recalled for playback to Earth, the data will continue to accumulate until the 5×10^5-bit core memory is full. At this time, the entry of further shock data may be inhibited unless the shock-front magnitude exceeds that of the data already in storage. In the latter case, the new data would over-write the old data in storage—thereby establishing a new threshold for entry of further shock data into storage. The system can, therefore, be made self-adjusting so that only the most significant shock data is retained in storage between memory readouts. By monitoring the level of solar activity in the real-time science telemetry stream, the *Helios* Mission Operations Team can make real-time decisions on the frequency with which they need to command a replay of shock data from storage.

C. *Helios* Telemetry Formats

As mentioned previously, all *Helios* telemetry data, whether they be science, engineering, blackout, or shock data, are digitally encoded and routed to the Distribution Unit. The Distribution Unit has seven modes of operation. These seven distribution modes may be conveniently grouped into five functional categories as depicted in the lefthand column of Table 1. Within any one distribution mode, one of several telemetry formats is available for selection in accordance with the second column of Table 1. In addition, each telemetry format has a range of information bit rates available in steps of a factor of two according to the listing provided in the third column of Table 1. The selection of a particular data mode, telemetry format, and bit rate for real-time transmission is done by ground command. Similar statements may be made for the Storage modes shown in Columns 4 and 5 of Table 1. With this in mind, it is appropriate to discuss the five functional distribution modes.

1. Distribution mode 0: real-time telemetry without memory read-in. This mode will usually be used when format 1 (high rate) or format 5 (very high rate) has been selected. It may be used during certain prelaunch tests, before experiment turn-on after launch, or when ascertaining the spacecraft's state of health after blackout—before all the blackout data that are in the memory have been transmitted back to Earth. However, it can be used at other times, and with any of the formats 1 through 5.

2. Distribution modes 1, 2 and 3: real-time telemetry with memory read-in. Scientific and engineering data, or engineering data alone, are combined in a selected format and sent to the RF subsystem for real-time transmission to Earth. At the same time, shock data are formatted and stored in the spacecraft core memory.

There are three real-time science formats[3] which can be selected, each associated with a different range of bit rates. These are the High, Normal and Reduced Rate Formats (Nos. 1, 2, and 3). Also, it is possible to use the engineering format (No. 4) and transmit to Earth only engineering data.

Simultaneously, the shock data are formatted (No. 6) and fed as a serial bit stream to the memory. The read-in address at the memory can be continually cycled, so that shock data may be held in storage for a fixed amount of time and then over-written by new data.

3. Distribution mode 4: real-time telemetry with memory read-in. This is a special case associated with *Subsection C-2*, above, wherein *engineering-only* data are transmitted to Earth and simultaneously read in to storage—both at a rate of 128 bps. Principal applications of this mode occur during the launch and initial DSN acquisition phases of the mission, and again during the Step I and Step II spacecraft maneuvers, i.e., times during which there is a reasonable probability of telemetry dropouts due to either lack of near-Earth station coverage or spacecraft antenna pattern nulls.

4. Distribution mode 5: blackout. The blackout mode is used whenever the spacecraft is occulted by the Sun. Both scientific and engineering data are formatted using format 3, and fed to the Core Memory for storage. The bit rate of the encoder is set very low, such that the memory will be efficiently used during the expected duration of the blackout. When the memory becomes full, the read-in process will be automatically stopped so that there will be no erasure or over-writing of the memory in this mode. This is in contrast to the shock mode memory which will permit an over-writing of the data.

5. Distribution mode 7: memory read-out. This mode is used whenever it is desired to read out science, engineering, shock, or blackout data that have been previously stored aboard the spacecraft. In this mode, the contents of the bulk memory are read out and transmitted to Earth without the addition of any real-time science or engineering data. Since the Core Memory data had been stored in digital form, it is unnecessary to use the Data Encoder, so the Core Memory data are fed directly to the Distribution Unit for processing to Earth. The read-out of the Core Memory is non-destructive, and after the memory has been completely read out, there is an automatic change of mode to the real-time telemetry *without* memory read-in mode. Thus, as little time as possible is spent in the memory read-out mode—however, if the transmission of the memory contents is unsatisfactory for any reason, the data are still available in memory for a second attempt. In addition, the memory read-out mode may be interrupted at any time by ground command without loss of the stored information. This latter feature was incorporated to allow the immediate return to the real-time telemetry mode in case of a suspected problem aboard the spacecraft, or to permit periodic sampling of real-time engineering data when the memory read-out process would consume considerable time due to very low bit rates.

D. Data Encoding System

A detailed description of the *Helios* telemetry data encoding and formatting system, including the bit-by-bit allocations within the 1152-bit *Helios* telemetry frame for each of the six formats, will be left to future articles. Of present importance to the reader is the fact that *Helios* has two separate encoding functions within the Telemetry System. The first is the Data Encoder that translates the raw science or engineering data into a digital structure

[3]These science formats also contain essential engineering data needed for proper conduct of the mission.

that is suitable for further processing within the telemetry subsystem. The second is the Convolutional Encoder that processes the data only after it has been formatted for transmission to Earth. Since confusion may otherwise result, it is important to keep in mind the foregoing adjectives since they will be used in the future articles.

IV. Conclusion

This article has presented several significant highlights resulting from the Fourth *Helios* Joint Working Group Meeting and its subsequent second meeting of the *Helios* Near-Earth Phase Study Group. It has also provided the reader with a functional description of the *Helios* Spacecraft Telemetry Subsystem. It is intended that the next article will treat the *Helios* Spacecraft Command System. Thus, this and the next article will provide a basis for discussing the mechanism and performance of the numerous uplink and downlink modes of operation of the spacecraft radio system in a subsequent article.

References

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2. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. III, pp. 20–28. Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1971.
3. *Project Helios Minutes of the Fourth Joint Working Group Meeting Held at the Goddard Space Flight Center, Greenbelt, Maryland, Apr. 28–May 4, 1971.* Goddard Space Flight Center, Greenbelt, Md.
4. *Project Helios Minutes of the Second Near-Earth Study Group Meeting Held at the Goddard Space Flight Center, Greenbelt, Maryland, May 5–7, 1971.* Goddard Space Flight Center, Greenbelt, Md.

Table 1. *Helios* telemetry: modes of operation

Distribution mode (DM)	Data conditioning for real-time transmission		Data conditioning for onboard storage	
	Format FM	Bit rate BM, bps	Format FM	Bit rate BM, bps
DM 0 Real time without memory read-in	FM 1 High rate FM 2 Normal rate FM 3 Reduced rate FM 4 Engineering FM 5 Very high rate	512–2048 64–512 8–64 8–4096 4096		
DM 1, 2, 3 Real time with memory read-in	FM 1 High rate FM 2 Normal rate FM 3 Reduced rate FM 4 Engineering	512–2048 64–512 8–64 8–4096	FM 6 Shock	4096 8192 16384
DM 4 Real time with memory read-in	FM 4 Engineering	128	FM 4 Engineering	128
DM 5 Black-out			FM 3 Reduced rate	8 (interrupted)
DM 7 Memory read-out	FM 3 Reduced rate FM 4 Engineering FM 6 Shock	8–4096 8–4096 8–4096		

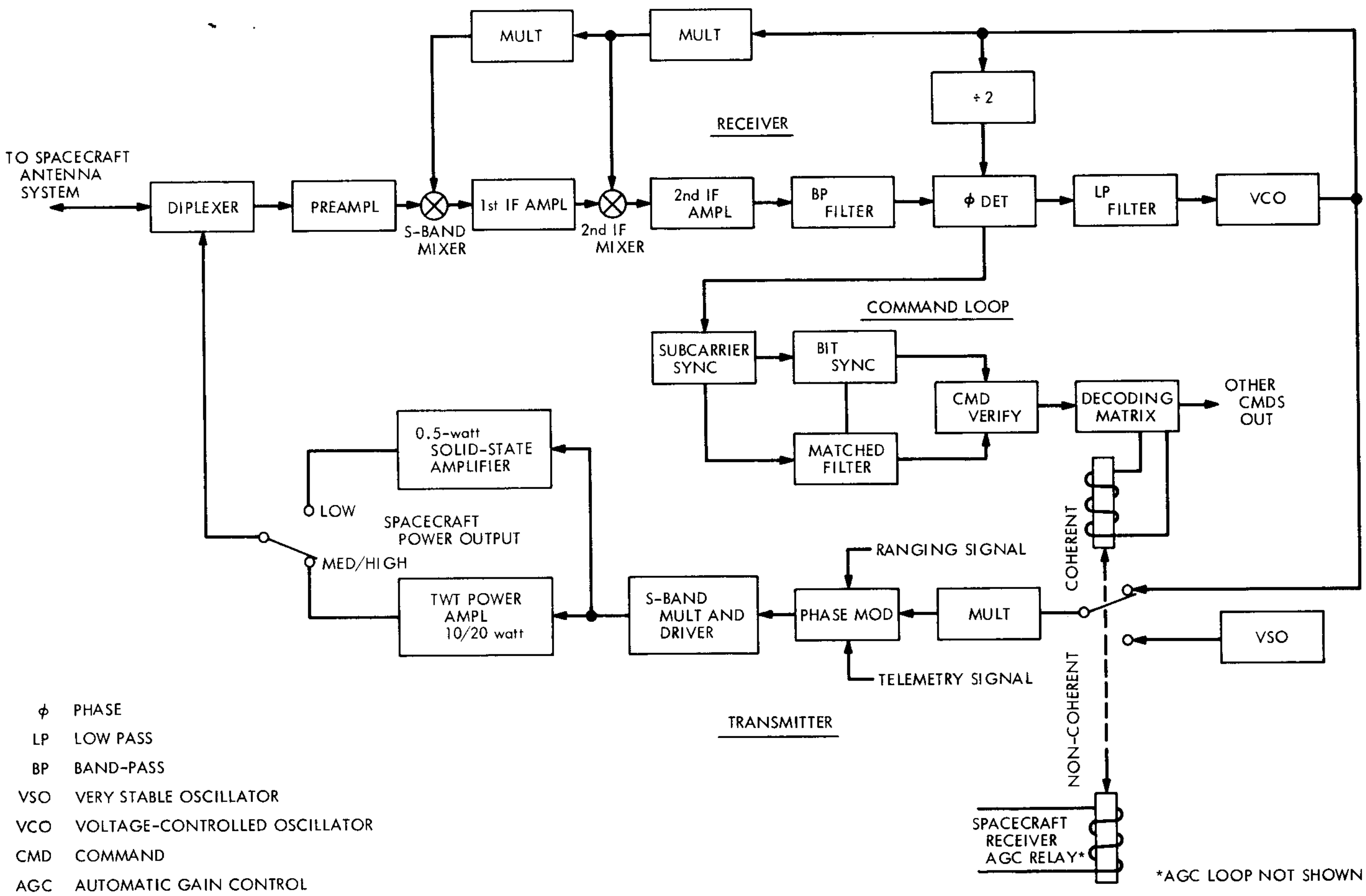

Fig. 1. Simplified diagram of *Helios* spacecraft transponder coherency mode control (only one channel shown)

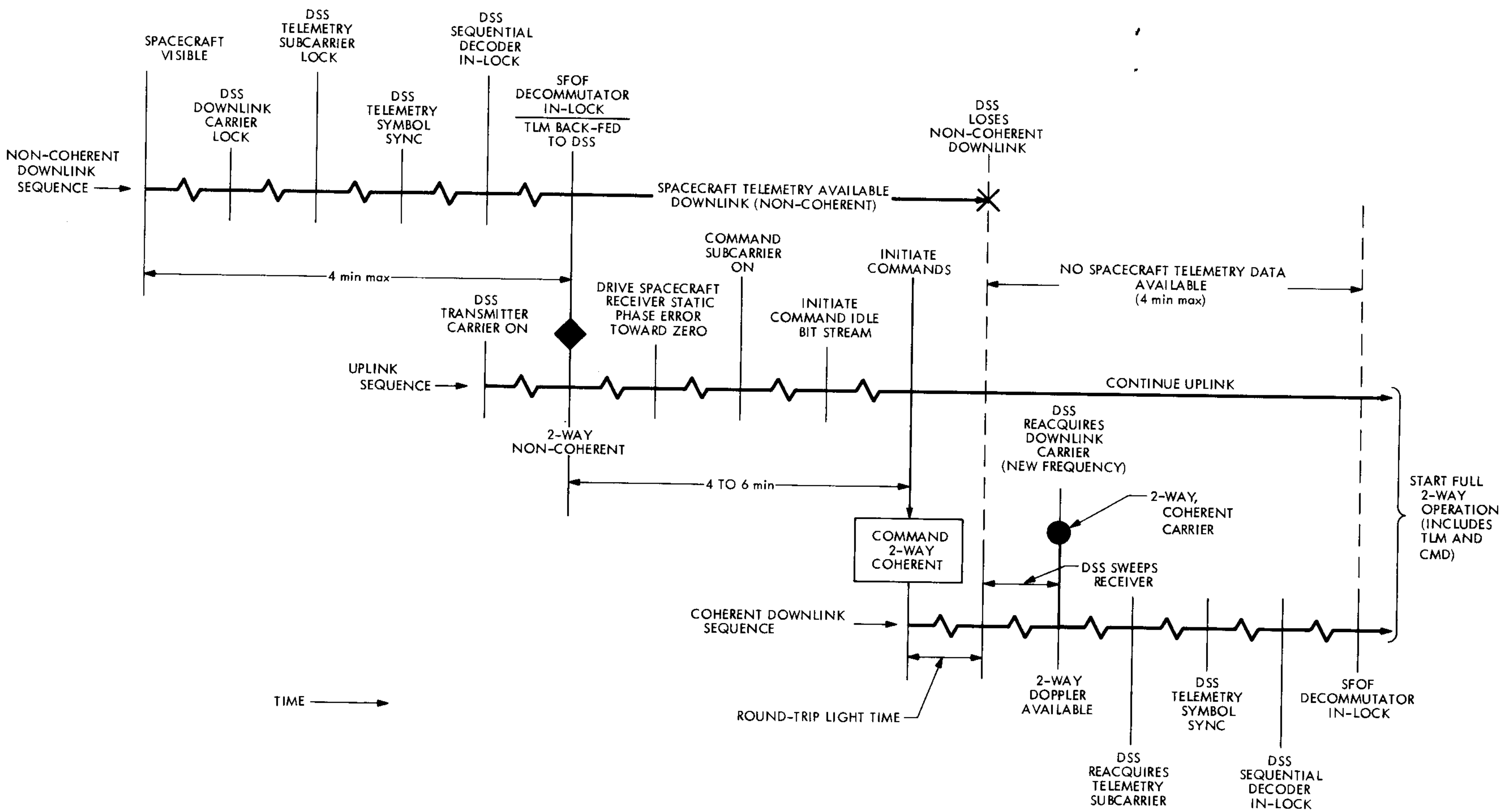

Fig. 2. DSN acquisition sequence for *Helios*

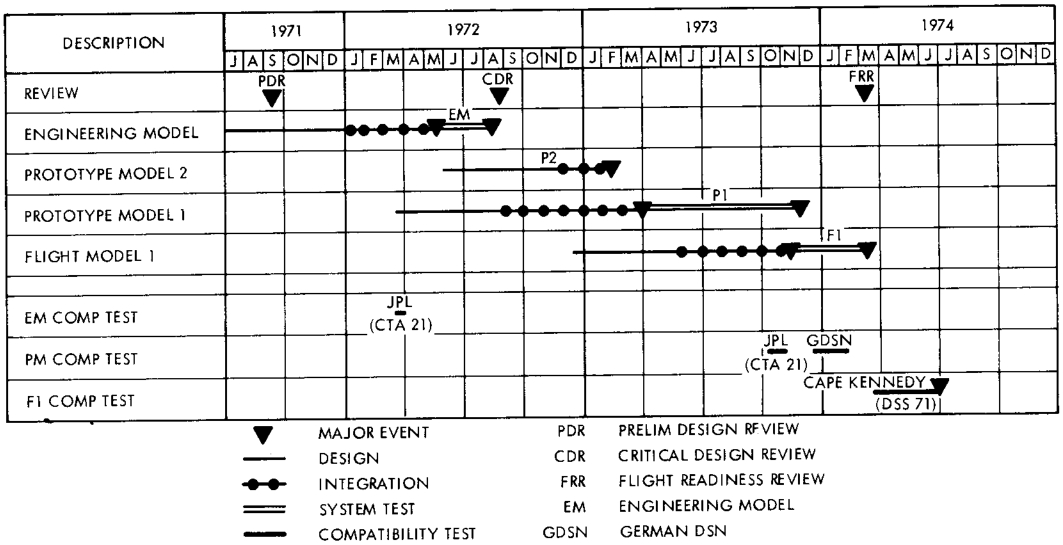

Fig. 3. Project *Helios* telecommunication subsystem: major milestones, April 1971

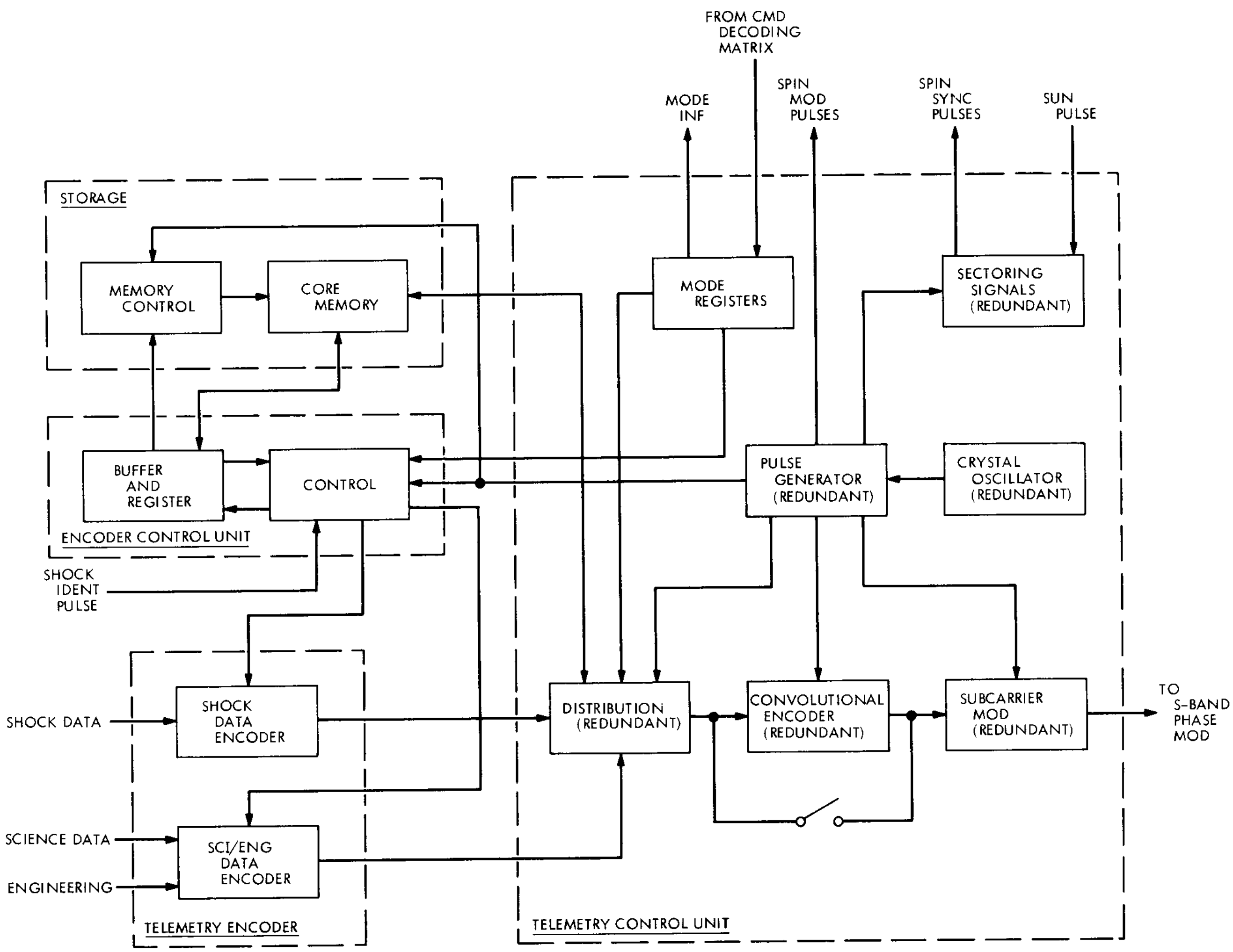

Fig. 4. Functional block diagram of *Helios* spacecraft telemetry subsystem